with both P_w and A_{wh} referenced to a 5 MHz bandwidth. When measured in a 1 MHz bandwidth, the peak power (P_m) would be:

$$P_m = P_w - 20 \log (5 \text{ MHz}/1 \text{ MHz}) = P_w - 14 \text{ dB}$$

The average power would be:

$$A_m = P_w - 27 \text{ dB} - 10 \log (5 \text{ MHz}/1 \text{ MHz}) = P_w - 34 \text{ dB}$$

This case is average power limited to -41.3 dBm/MHz, if the peak power is determined in the bandwidth of the pulse (e.g., the peak power is limited to 0 dBm in 5 MHz, $P_w = 0$ dBm).

$$-41.3 = P_w - 34 \text{ dB}$$

$$P_w = -7.3 \text{ dBm}$$

In the 400 MHz bandwidth, the EESS receiver would see 40 hop channels (400/1000 x 100). The determination of the average power in the 400 MHz bandwidth requires first computing the effective duty cycle. The duty cycle of the complete waveform was previously shown to be - 10 log (PRF x PW) = 7 dB. However, in the 400 MHz bandwidth only an effective 40 out of 100 hopping channels will be seen. Thus, the PRF used in the waveform duty cycle determination must be reduced by the ratio of 40/100. This effective duty cycle is then:

$$DC_e = -10 \log (\text{PRF} \times 0.4 \times \text{PW}) = 11 \text{ dB}$$

and the average power is 11 dB below the peak power or -7.3 dBm -11 dB = -18.3 dBm

Pulsed FH Signal (No Overlap of Hop Channels)

For this analysis, the following pulsed FH system characteristics are considered:

Hopping frequency range - 1 GHz with hopping through out the 23.6 to 24 GHz band;

Number of hop channels - 200, resulting in a 5 MHz spacing between hop channels;

PW - 0.2 microseconds, resulting in a pulse bandwidth of 5 MHz;

Hopping sequence - sampling without replacement to define the order for one cycle. This cycle is then repeated resulting in the return to each hopping channel on a regular periodic basis;

PRF - 1 MHz.

The duty cycle of the hopping waveform is

$$DC = -10 \log (\text{PRF} \times \text{PW}) = 7 \text{ dB}$$

For an individual hopping channel, the duty cycle, because of the hopping sequence assumed, would be:

$$DC_h = -10 \log (PW \times PRF/\text{No. of channels}) = 30 \text{ dB}$$

If the peak power of a pulse is set to P_w, then the average power on a single hop channel would be

$$A_{wh} = P_w - 30 \text{ dB}$$

with both P_w and A_{wh} referenced to a 5 MHz bandwidth. When measured in a 1 MHz bandwidth, the peak power (P_m) would be:

$$P_m = P_w - 20 \log (5 \text{ MHz}/1 \text{ MHz}) = P_w - 14 \text{ dB}$$

The average power would be:

$$A_m = P_w - 30 \text{ dB} - 10 \log (5 \text{ MHz}/1 \text{ MHz}) = P_w - 37 \text{ dB}$$

This case is average power limited to -43.1 dBm/MHz, if the peak power is determined in the bandwidth of the pulse (e.g , the peak power is limited to 0 dBm in 5 MHz, $P_w = 0$ dBm).

$$-41.3 = P_w - 37 \text{ dB}$$

$$P_w = -4.3 \text{ dBm}$$

In the 400 MHz bandwidth, the EESS sensor receiver would see 80 hop channels (400/1000 x 200). The determination of the average power in the 400 MHz bandwidth requires first computing the effective duty cycle. The duty cycle of the complete waveform was previously shown to be - 10 log (PRF x PW) = 7 dB. However, in the 400 MHz bandwidth only an effective 80 out of 200 hopping channels will be seen. Thus, the PRF used in the waveform duty cycle determination must be reduced by the ratio of 80/200. This effective duty cycle is then

$$DC_e = -10 \log (PRF \times 0.4 \times PW) = 11 \text{ dB}$$

and the average power is 11 dB below the peak power or -4 3 dBm -11 dB = -15.3 dBm

ASSESSMENT OF PEAK POWER TO EESS SENSOR RECEIVERS

The interference impact to EESS sensors is based on the aggregate average power from a number of vehicular radars. The average power from one radar is below the EESS sensor interference threshold However, the question of whether the peak power from a vehicular radar would exceed the interference threshold of the EESS sensor was also addressed. The peak power from a number of vehicular radars will not increase due to the aggregation effect, rather the peak power from an individual vehicular radar is of concern. For an impulse UWB vehicular radar, the peak power is limited to 0 dBm/50 MHz and will increase by 20 Log (400 MHz/50 MHz) in the 400 MHz sensor bandwidth For the pulsed FH vehicular radars the peak power is limited to 0 dBm/50 MHz or to 0 dBm if the individual pulsed FH vehicular radar has a bandwidth narrower than 50 MHz. Regardless of the pulsed FH pulse bandwidth, the peak power in the sensor bandwidth cannot exceed 0 dBm + 20 Log (400 MHz/50 MHz) and in most cases is expected to be no greater than 0 dBm. Thus, the analysis using 0 dBm + 20 Log (400

MHz/50 MHz) is applicable to impulse radars and is the limiting condition for pulsed FH vehicular radars The link budgets shown in Tables E-1 through E-4 examine the impact that the peak power will have on the EESS sensor receivers operating in the 23.6-24 GHz band. As shown in Tables E-1 through E-4 the peak power is below the interference threshold. Based on the results of this analysis if the peak power of the pulsed FH signal is limited to 0 dBm/50 MHz there will not be a problem.

The interference threshold for 23.6-24 GHz EESS sensors used in this analysis are the same as the one used to develop the current UWB vehicular radar rules. This interference threshold is specified in International Telecommunication Union - Radiocommunication Sector (ITU-R) Recommendation SA.1029.[5] The interference criteria in ITU-R SA.1029 are regularly updated to reflect improvements in the sensitivity of the sensors, and to take advantage of other technological advances. Since the original analysis was performed by NTIA, the interference criteria of the EESS sensors operating in the 23.6 - 24 GHz has been lowered by 6 dB (e.g., -160 dBW/200 MHz to -166 dBW/MHz). Increasing the interference protection requirements for EESS sensors reduces the available margin.

Table E-1.

Parameter	Value	Comment
Center Frequency (MHz)	23800	Center Frequency of 23600-24000 MHz EESS Band
Sensor Orbital Altitude (km)	705	AMSR-E Sensor Specification
Peak EIRP (dBW/50 MHz)	-30	Peak EIRP Limit Specified in Section 15 515(e)
Conversion from Measurement Bandwidth to EESS Sensor Bandwidth (dB)	18	20 Log (400 MHz/50 MHz)
Peak EIRP (dBW/400 MHz)	-12	Peak EIRP Limit Referenced to EESS Bandwidth
EIRP Reduction (dB)	-25	Reduction of EIRP in Direction of EESS Sensor as Specified in Section 15.515 (c)
Free Space Propagation Loss (dB)	-180 9	Based on Slant Range of 1120 km
Atmospheric Loss (dB)	-1	ITU-R Recommendation P 676
Sensor Mean Antenna Gain (dBi)	45 2	AMSR-E Sensor Specification 46.7-1 5 dB
Receiver Power at the Sensor (dBW/400 MHz)	-173 7	
Interference Threshold (dBW/400 MHz)	-157	ITU-R Recommendation SA 1029-1
Available Margin (dB)	16 7	Difference Between Received Power at the Sensor and the Interference Threshold

[5] International Telecommunication Union-Radiocommunications Sector, Recommendation SA.1029-2, *Interference Criteria for Satellite Passive Remote Sensing* (2002).

Table E-2.

Parameter	Value	Comment
Center Frequency (MHz)	23800	Center Frequency of 23600-24000 MHz EESS Band
Sensor Orbital Altitude (km)	833	AMSU-A Sensor Specification
Peak EIRP (dBW/50 MHz)	-30	Peak EIRP Limit Specified in Section 15.515(e)
Conversion from Measurement Bandwidth to EESS Sensor Bandwidth (dB)	18	20 Log (400 MHz/50 MHz)
Peak EIRP (dBW/400 MHz)	-12	Peak EIRP Limit Referenced to EESS Bandwidth
EIRP Reduction (dB)	-25	Reduction of EIRP in Direction of EESS Sensor as Specified in Section 15 515 (c)
Free Space Propagation Loss (dB)	-178 4	At Nadir
Atmospheric Loss (dB)	-1	ITU-R Recommendation P 676
Sensor Mean Antenna Gain (dBi)	34 5	AMSU-A- Sensor Specification 36-1.5 dB
Receiver Power at the Sensor (dBW/400 MHz)	-181 9	
Interference Threshold (dBW/400 MHz)	-157	ITU-R Recommendation SA 1029-1
Available Margin (dB)	24 9	Difference Between Received Power at the Sensor and the Interference Threshold

Table E-3.

Parameter	Value	Comment
Center Frequency (MHz)	23800	Center Frequency of 23600-24000 MHz EESS Band
Sensor Orbital Altitude (km)	825	ATMS Sensor Specification
Peak EIRP (dBW/50 MHz)	-30	Peak EIRP Limit Specified in Section 15 515 (e)
Conversion from Measurement Bandwidth to EESS Sensor Bandwidth (dB)	18	20 Log (400 MHz/50 MHz)
Peak EIRP (dBW/400 MHz)	-12	Peak EIRP Limit Referenced to EESS Bandwidth
EIRP Reduction (dB)	-25	Reduction of EIRP in Direction of EESS Sensor as Specified in Section 15.515 (c)
Free Space Propagation Loss (dB)	-178 3	At Nadir
Atmospheric Loss (dB)	-1	ITU-R Recommendation P.676
Sensor Mean Antenna Gain (dBi)	31	ATMS Sensor Specification 32 5-1 5 dB

Receiver Power at the Sensor (dBW/400 MHz)	-185 3	
Interference Threshold (dBW/400 MHz)	-157	ITU-R Recommendation SA 1029-1
Available Margin (dB)	28 3	Difference Between Received Power at the Sensor and the Interference Threshold

Table E-4.

Parameter	Value	Comment
Center Frequency (MHz)	23800	Center Frequency of 23600-24000 MHz EESS Band
Sensor Orbital Altitude (km)	816	CMIS Sensor Specification
Peak EIRP (dBW/50 MHz)	-30	Peak EIRP Limit Specified in Section 15.515(e)
Conversion from Measurement Bandwidth to Sensor Bandwidth (dB)	18	20 Log (400 MHz/50 MHz)
Peak EIRP (dBW/400 MHz)	-12	Peak EIRP Limit Referenced to EESS Bandwidth
EIRP Reduction (dB)	-25	Reduction of EIRP in Direction of EESS Sensor as Specified in Section 15 515 (c)
Free Space Propagation Loss (dB)	-182 5	Based on Slant Range of 1331 6 km
Atmospheric Loss (dB)	-1	ITU-R Recommendation P 676
Sensor Mean Antenna Gain (dBi)	52	CMIS Sensor Specification 53 5-1 5 dB
Receiver Power at the Sensor (dBW/400 MHz)	-168 5	
Interference Threshold (dBW/400 MHz)	-157	ITU-R Recommendation SA 1029-1
Available Margin (dB)	11 5	Difference Between Received Power at the Sensor and the Interference Threshold

SUMMARY

The comparative interference power at the output of the EESS sensor receiver and whether or not the signal is limited by the peak or average power are summarized in Table E-5.

Table E-5.

Signal Type	Average or Peak Power Limited	Comparative Interference Power (dBm/400 MHz)
10 MHz PRF Non-Dithered Impulse	Average Power Limited	-25 3
1 MHz PRF Non-Dithered Impulse	Average Power Limited	-15 3
Dithered Impulse	Peak Power Limited	-18
Pulsed FH (Partial Overlap of Hop Channels)	Peak Power Limited	-24.9

Pulsed FH (Complete Overlap of Hop Channels)	Peak Power Limited	-24 8
Pulsed FH (No Overlap of Hop Channels)	Peak Power Limited	-24 9
Pulsed FH (No Overlap of Hop Channels)	Average Power Limited	-18 3
Pulsed FH (No Overlap of Hop Channels)	Average Power Limited	-15 3

As shown in Table E-5, the interference power levels of the pulsed FH signals are comparable to the non-dithered impulse and dithered impulse signals. The values shown in the table must be further adjusted for propagation loss, antenna gains, etc. to estimate the actual interference power from the one radar. However, these extra loss values should be the same across all the signal cases being analyzed, and have no effect on a comparative analysis. Thus, for the pulsed FH signal characteristics considered, one pulsed FH radar should be no worse, from an interference standpoint, than one impulse radar.

This analysis is applicable only to assessing the interference impact to an EESS sensor receiver, because the effective interference signal at a space-borne sensor is an aggregate from a large number of vehicular radars. In addition, this aggregate signal is of concern over an extensive frequency range because the sensors are wide bandwidth devices. Thus, the frequency hopping of an individual radar as a part of an aggregate has a different impact in this case than frequency hopping devices would have in other bands where they might operate in close proximity to relatively narrowband ground-based receivers. For ground-based receivers, a single frequency hopping transmitter would be dominant in setting the effective interference power level and only a relatively narrow frequency range is of primary concern. Thus, the results of this analysis cannot be extended to assess the potential interference of a pulsed FH signal on ground-based receivers

For the pulsed FH, the worst practical case would appear to be a hopping frequency range of 1 GHz, since this covers the entire 23 6-24 GHz EESS band, given the limitation that the center frequency must be located above 24.075 GHz. As shown in the analysis, the number of hop channels is not a factor. The average power in the 400 MHz sensor bandwidth would be -15.3 dBm (-41.3 + 10 Log (400)). For an average power of -41.3 dBm the same average power is in a 400 MHz bandwidth as the limiting impulse case considered in the study previously performed by NTIA

It should be noted that the peak and average power measurements must be performed at the maximum values across the 23.6-24 GHz frequency band. The compatibility of pulsed FH signals with EESS sensor receivers will not be impacted by the frequency hopping pattern employed (e.g , psuedo random). However, for the compliance measurements and compatibility it is important that the Commission's Rules require the frequency hopping channels to be used on a regular periodic basis. These issues will be addressed in greater detail in the proposed measurement procedures